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Laser Source for the γ-γ Collider

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Introduction

The Next Linear Collider (NLC) offers an opportunity to use high energy photon collisions to probe basic particle structures. The production of high energy gammas from collisions between the NLC high energy electrons and low energy photons places difficult requirements on the laser low energy photon source [1].

The photon wavelength must be approximately one micron since longer wavelengths will decrease the electron utilization efficiency, and shorter wavelengths will open a loss channel for gammas through electron pair creation. The laser pulse format must match the electron generation format of the NLC. The electrons are produced in macro-pulses at 120 Hz. Each macro-pulse consists of around 100 subpulses separated by 2.8 nanoseconds. To interact efficiently with the electrons the laser subpulses must have approximately a 2 picosecond pulse duration. Analysis of the photon densities required for efficient utilization of the electrons and the focusing capabilities of the final photon injection optics leads to a required photon sub-pulse energy of approximately one joule. Thus the laser macro-pulse energy must be 100 joules at 120 Hz. The laser average power will be 12 kW.

Laser Options

There are no current lasers that meet all these requirements, and there are few lasers that work near these average powers. High power industrial processing lasers usually have lower pulse energies and much higher pulse repetition rates. High power military laser are usually continuous wave lasers. High pulse energies at one micron wavelengths have been utilized in laser fusion experiments, but these lasers normally can be fired only at several hour intervals.

Two approaches were considered for meeting the laser requirements. One approach would extend commercial one micron Nd:YAG laser technology to pulse energies of one joule and pulse rates of 120 Hz. This extension would be only a modest risk laser development. The technology to convert the normal several nanosecond pulses of such lasers to the picosecond range has been demonstrated. The outputs of 100 such lasers would have to be combined to produce the 100 J macro-pulses. The beam combination system would require optical switches that opened in one nanosecond and could handle average powers up to 12 kW. A major development program would be required for such switches, and the program would involve notable risk.

A second approach is to increase the pulse repetition rate of the laser fusion high pulse energy lasers. The laser fusion program already has such a laser under development in the Mercury Laser Project. The efficient generation of short laser pulses requires the use of storage lasers that can be energized slowly and then discharged in very short times. Most such lasers are solid state lasers and face significant problems in removing the waste heat from the laser by conduction. The Mercury laser (Fig.1) was designed to address this thermal management problem.

The Mercury laser will operate at 10 Hz with 100 J pulses. Twelve such lasers would have to be time multiplexed to achieve the γ-γ laser requirements. At these low pulse rates the beam combination optical system will not be difficult. The major challenge will the modification of the Mercury laser pulse format which is for a single, several nanosecond long pulse. Achieving the desired diffraction limited beam quality will also be an important challenge.

Mercury Laser Project

The Mercury laser utilizes three primary innovations to achieve the goal of a high efficiency, high repetition rate laser driver for laser fusion experiments. The removal of heat from the laser media is accomplished by flowing helium at high speed over the surface of thin laser slabs. The thermal gradients in the laser media are in the short dimension for effective conductive cooling and are in the direction of the laser propagation to minimize the optical distortion. The low index of refraction of helium minimizes the helium thermal-optical distortions that must later be removed with adaptive optics. Figure 2 shows the arrangement of thin laser slabs imbedded in flow vanes within

Fig.1 - The diode-pumped solid state Mercury laser is a high pulse rate, next generation laser fusion driver

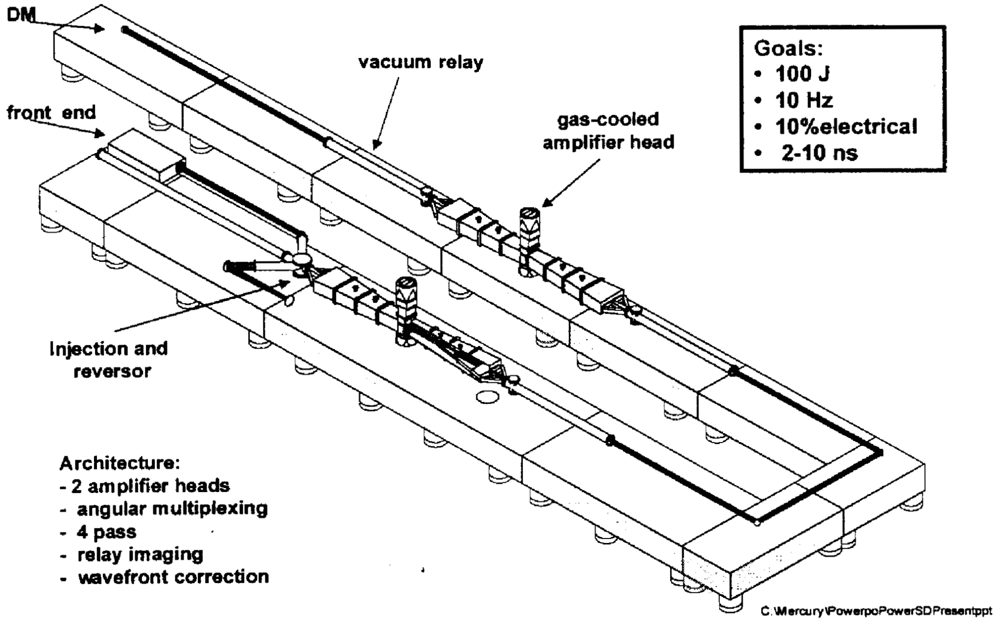
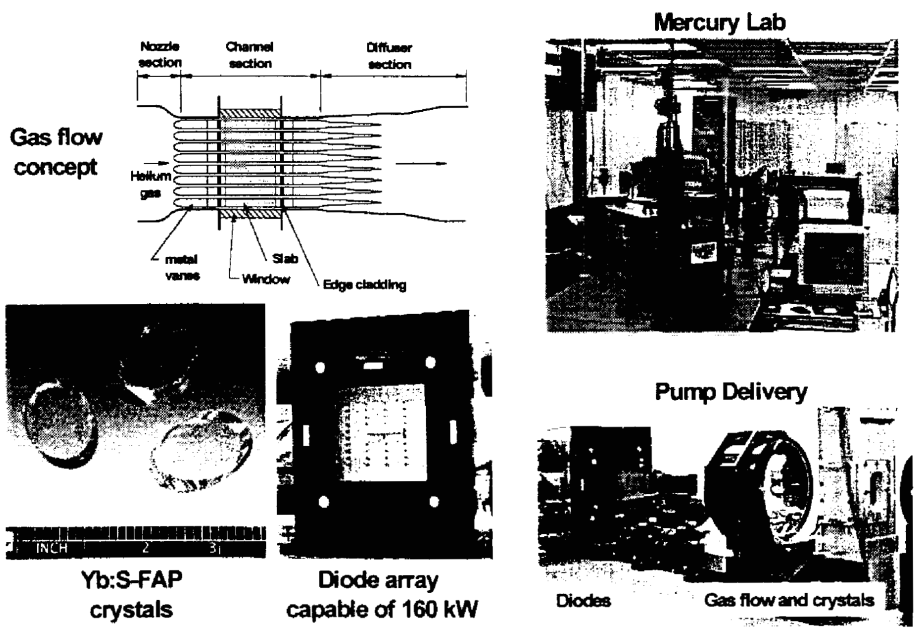


Fig. 2 - The Mercury laser will utilize three key technologies: gas cooling, diodes, and Yb:S-FAP crystals to deliver 100 J at 10 Hz with 10% efficiency



the helium flow duct. Full scale demonstrations have validated the flow and thermal models have confirmed that the design meets the optical system requirements.

The second innovation is the use of diode lasers rather than flash lamps to energize the laser media. The narrow frequency output of the diode laser is matched to the absorption band of the laser media. The efficient coupling and the efficiency of diode lasers results in significantly higher pumping efficiency of the laser media and also significantly lowers the waste heat that must be removed by the helium cooling system. The primary challenge for the diode laser design is minimizing the high capital cost of the diode laser and their packaging design. LLNL has developed a low cost packaging design that also efficiently couples the diode light into the laser slabs. This design has been produced under commercial contract and will be tested this year in the Mercury laser laboratory.

The third innovation is the use of Yb:S-FAP as the laser media instead of the usual Nd-glass. This crystalline media has better thermal conductivity for cooling, longer storage lifetime for efficient pumping, and a high quantum efficiency to minimize waste heat. The growth of these new crystals (Fig. 2) with adequate size and optical quality has been the primary technical challenge in the Mercury project. Crystals grown recently may satisfy these requirements, but some testing remains to be done.

The Mercury laser has two amplifier heads and a four pass optical system. This year one amplifier head and the full optical configuration will be tested in the Mercury laboratory. A second amplifier head must be constructed before full power extraction can be demonstrated.

Modified Pulse Format

The Mercury laser currently is designed to produce a 100 J pulse lasting several nanoseconds. To generate a 100 J macro-pulse consisting of 100 pulses of 2ps and 1 J each, we have to use a pulse compression technique utilizing diffraction gratings [2]. If a laser has adequate gain bandwidth, then the laser pulse can have a frequency chirp and still be amplified. Starting with a short, low power 2ps pulse, this pulse is spread in angle by a diffraction grating. The optical layout has different pathlength for different frequencies so that when the frequencies are recombined, the resulting laser pulse is several nanoseconds long. This long pulse can then be sent through the Mercury amplifier to generate the 1 J sub-pulse. After exiting the amplifier the laser pulse passes through another optical system with a diffraction grating that reverses the path length differences of the first grating system. The result is a 1 J pulse that is only 2 ps in duration.

If the low power front end of the laser generates a series of 100 low power pulses each 2ps long and separated by 2.8 ns, then this pulse format can be sent through the same optics and amplifier. The stretched pulses will overlap to give a 300 ns pulse to be injected into the Mercury amplifier. The final pulse compression optics will then produce the desired pulse format.

The bandwidth of Yb:S-FAP is adequate to generate 2ps pulses, but the variations in gain over that bandwidth will significantly distort the laser pulse. This effect can be countered by the technique of spectral sculpting of the low power input laser pulse. The input pulse has its amplitude modified for different frequencies such that the amplitude variation counters the gain variation and produces a proper final pulse shape. We have generated amplifier performance calculations for the Mercury amplifier that show the required spectral sculpting needed to give the desired 100 J output macro-pulse from a shaped 25 mJ input pulse.

The Laboratory for Laser Energetics at the University of Rochester is under contract to perform an experimental demonstration of this technique this spring for the laser fusion program. The experimental parameters are close enough to our requirements to provide a validation of this technique for the γ-γ laser.

Plans for FY01

This year we will develop conceptual design for the major modifications needed to adapt the Mercury laser to this mission. A design of the stretcher/compressor optical system and the required diffraction grating will be generated. A spectral sculpting system concept will be based on the results from the experimental program. A new laser front end (oscillator and pre-amplifiers) will be designed to provide the needed Mercury input signal. The objective will be to have an end-to-end design that identifies all the risk elements in the system and outlines any needed risk reduction efforts.

Under the separately funded Mercury laser program, an amplifier head will be completed and tested in the Mercury laboratory with the complete optical configuration. A modified Mercury optical design will also be designed for the 300 ns long macro-pulse needed for the γ-γ laser.

References

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